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Catalogue of candidate emission-line objects in the Small Magellanic Cloud

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ABSTRACT

Hα and [O III] narrow band, wide field (7×7 degree), CCD images of the Small Magellanic Cloud were compared and a catalogue of candidate planetary nebulae and Hα emission-line stars was compiled. The catalogue contains 131 planetary nebulae candidates, 23 of which are already known to be or are probable planetary nebulae or very low excitation objects. Also, 218 emission-line candidates have been identified with 113 already known. Our catalogue therefore provides a useful supplement to those of Meyssonnier & Azzopardi (1993) and Sanduleak, MacConnell & Davis Phillip (1978). Further observations are required to confirm the identity of the unknown objects.

Key words: methods: observational – catalogues – astrometry – planetary nebulae: general – Magellanic Clouds

1 INTRODUCTION

Many of the salient features of our nearest neighbour galaxies, the Magellanic Clouds, have been well determined. Their proximity also allows us to further develop standard candle techniques for distance determination (e.g., Di Benedetto 1997; Sasselov et al. 1997, but see Udalski et al. 1998). Many classes of objects in our own galaxy have been identified in the Clouds (see, e.g., Keller & Bessell 1998; Mantegazza & Antonello 1998; Santengelo 1998) and their presence has allowed us a close view of some of the shorter time scale astrophysical events, such as supernova 1987a.

However, it remains that *the content* of the Clouds is not extensively explored. In particular, only 65 proven or probable planetary nebulae (PN) candidates are known in the area of the Small Magellanic Cloud (SMC) that is studied here (previous catalogues are contained in Meyssonnier & Azzopardi (1993), hereafter referred to as MA93, and in Sanduleak, MacConnell and Davis Phillip (1978), hereafter referred to as SMP78). Many fainter PN were found by Jacoby (1980) and Morgan & Good (1985). However, these objects are beyond the detection limits of the current work. It is the aim of this work to provide a more spatially complete catalogue of the bright PN and emission-line object content of the SMC. We also describe a new method of selecting candidate objects which is highly suited to studies of the Magellanic Clouds.

Cataloguing any class of Galactic astronomical object requires a large solid angle of sky to be observed. In the case of the SMC, however, the entire galaxy subtends only ~ 10 square degrees on the sky. Thus, the entire SMC can be observed in different frequency bands with few exposures of an extremely wide field telescope or camera, allowing us to survey more completely the population of specific classes of objects than by carrying out surveys in the Galaxy. Estimates of the population in the Magellanic Clouds may therefore provide further insight into the true population in the Galaxy.

Wide field telescopes have had limited use in the recent past. However, the potential of automated patrol telescopes with a wide field format is now starting to be realized (see, eg., Carter et al. 1992), especially when used to observe transient and oscillatory sources. For the present work, we have used images of the SMC taken with a Nikon survey camera with an approximate 7×7 degree field.

Searching for PN candidates in the Clouds is facilitated by their strong emission in the Hα and [O III] bands. The gaseous ejecta is abundant in both hydrogen and oxygen and the remnant star is hot enough to doubly ionize oxygen with its UV continuum radiation. Thus, Hα and [O III] band images can be used to find PN candidates in the SMC.

The basic method for compiling the catalogue of PN candidates is therefore clear. We compare different waveband images of the SMC and identify objects which appear in all frames or in only an individual frame. The different

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emission properties of the sources then allow us to identify each object as a PN or as an Hα emission line star.

The remainder of the paper is organised as follows. In Section 2 we detail our observations and in Section 3 we discuss the data reduction process. Section 4 describes the methods of data analysis in more detail, discussing first the methods of selecting potential PN candidates. We then detail the photometric analysis used to determine the magnitudes of each identified source in each waveband relative to that of the relevant continuum. In Section 5 we outline the main features of the catalogue which we present in Tables 1 and 2. We make our concluding remarks in Section 6.

2 OBSERVATIONS

The wide field imaging project commenced in late 1996 and observations of the SMC were made in October and November 1996 and 1997. We have used images of the SMC taken with a Nikon survey camera with a 400mm f/4.5 Nikkor lens (aperture = 90 mm) which was fitted to the equatorial mount of the Boller and Chivens 16 inch telescope at Siding Spring Observatory. The original telescope tube and mirror were removed from the mount. When coupled with a 2048×2048 pixel CCD, this configuration provides a scale of 12 arc sec/pixel and covers an approximate $7{\times}7$ degree field.

Interference and glass filters were inserted between the camera lens and the CCD dewar necessitating a change of focus for each filter. The Hα filter was centered at 657.0 nm and had a FWHM of 1.5 nm; [OIII] at 501.6 nm, FWHM 2.5 nm; H(continuum) at 667.6 nm, FWHM 5.5 nm; and V 550.0 nm, FWHM 85 nm. When placed in the f/4.5 beam, the effective wavelengths of these filters are shifted blueward to the nominal transition frequencies of the relevant lines. For each filter, a sequence of 3 consecutive exposures were taken to enable cosmic rays to be rejected. Fifteen minute unguided exposures were made for the interference filters and 5 mins for the coloured glass broad band filters. The final summed Hα and [OIII] images comprised $3{\times}3$ exposures of 15 min length; H(cont.) and V images were of $3{\times}15$ and 3×5 min length respectively.

3 DATA REDUCTION

So as to remove effects due to pixel-to-pixel changes in CCD sensitivity, the images were bias subtracted and divided by flat field exposures using the IRAF† task CCDPROC. The flat field was a white screen suspended from the telescope dome and illuminated indirectly by normal tungsten incandescent lights. The three individual images for each filter were combined using GEOMAP and GEOTRAN. The positions of between one hundred and two hundred stars across the field were measured in order to generate these transformations. The combining of the sets of three images was done using a median filter which enabled the rejection of cosmic rays and, for some images, where we had moved the telescope in declination between exposures, the rejection of bad columns and pixels. We later combined the images taken on different nights with the same filter in the same way.

† IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

4 DATA ANALYSIS

We first compare images of the SMC in the Hα and [OIII] bands, noting all objects appearing in both frames. Continuum sources also appear in both images and so all objects can be checked against an (Hα − H(cont.)) and an ([OIII] − V) image. Objects appearing in the (Hα − H(cont.)) image and the [OIII] image can then be compiled. These objects can then be checked in the ([OIII] − V) image, resulting in a list of planetary nebulae candidates and an incomplete list of potential Hα emission-line stars.

4.1 Object Identification and Astrometry

The 2048×2048 images were trimmed to 1400×1400 pixels so as to include only the entire SMC. All images were then registered to the Hα frame using GEOMAP and GEOTRAN. After attempting to identify candidate objects using various software packages, we found that the most efficient search technique was a combination of visual scanning and threshold identification using the DAOFIND procedure within IRAF. A search using only threshold methods was found not to be optimal due to the fact that the focus of the camera was different for different filters. This led to sharp gradients in pixel value near stellar features in the (Hα − H(cont.)) and ([OIII] − V) frames which presents a serious problem for threshold detection. The CCD chip also showed several faulty columns and some bright and dark cluster faults. Consequently, the large pixel value gradients in such regions led to DAOFIND selecting whole columns of points and a large number of points in the area of localized faults.

Initially, three images were compared visually: (Hα − H(cont.)), a Gaussian filtered or 'smoothed' (Hα − H(cont.)) and [OIII]. 'Blinking' between each registered frame revealed which objects truly appeared in each frame. As a further aid to the search, DAOFIND was applied with optimal parameters to the 'smoothed' (Hα − H(cont.)) image, resulting in a list of co-ordinates of sharp peaks in pixel value. We attempted to apply a 5σ detection threshold on all objects but, as we have discussed above, this was found not to be optimal for detection of true object candidates. This problem was compounded by the fact that many objects lay in regions of the CCD where many stellar and diffuse emission features were found. Consequently, applying a threshold criteria to these 'bright' regions of the CCD was clearly not the most effective identification method. Because of the length of time needed to scan the images by eye, a constant criteria of object selection is difficult to maintain. We were mindful of this fact whilst comparing the images and, in any case, all selected objects were inspected at a later date with very few discarded.

It was noted during the selection process that the position of some objects on the image differed slightly between frames. This difference was less than one pixel in all cases and was only appreciable when the object appeared quite large (at least 2.5 pixels FWHM). Some of the objects are

therefore assigned a larger positional error. We also note that such 'large' objects are unlikely to be PN since a FWHM of > 2 pixels would imply that these objects have a spatial extent > 6 pc. Such a large PN would be too faint to be detected using our methods and we suggest that such objects may be interesting HII regions. In many cases (approximately half of the objects), especially for objects in the bright regions of the images and for faint objects, the object examination package, IMEXAMINE, was unable to determine a position on the image. This was overcome by two methods depending on the pixel value profile of the object in question:

(i) For objects found by the DAOFIND procedure, the positions of the objects were taken as those determined by DAOFIND itself. In cases where both IMEXAMINE and DAOFIND were successful, the position of the object was taken as the average of the two sets of co-ordinates. These two positions never differed by more than 0.1 pixels.

(ii) For objects that were not found by DAOFIND, the centroid was determined by visual inspection and by use of the SURFACE PLOT feature in IRAF. The approximate pixel number of the pixel containing the centroid was taken as the position of the object on the image. Importantly, these objects were generally very faint and this facilitated such visual centroiding. These objects are presented in the second part of the catalogue and one should allow at least 15 arc seconds of error ($\sim 3\sigma$) in their position.

Finally, objects in a list of strong (Hα − H(cont.)) sources were compared in the [OIII] and ([OIII] − V) images and objects not appearing in the ([OIII] − V) image were labelled as emission-line star candidates. This yields an incomplete catalogue of Hα emission-line stars as only those which have a 'visible' continuum at the [OIII] filter wavelength (λ = 5016 Å) will appear in this sample. Also appearing in this sample will be any heavily reddened PN. If extinction in the [OIII] spectral region is high enough then these PN will be labelled as Hα emission-line stars using our methods. We note that 218 emission line star candidates appear in the catalogue, only 113 of which are already known, marking a significant increase in our knowledge of the emission line star content of the SMC. We are, however, unable to estimate the completeness of this sample.

From the resulting list of co-ordinates for the selected candidates we can find the stellar co-ordinates to high enough precision using the ASTROMETRY package given a large enough set of reference stars. We obtained such a set from the NASA Guide Star Catalogue (1992). The reference stars were selected as easily identifiable, bright stars which appeared to have a uniform Gaussian-like brightness profile. 44 reference stars which satisfied these criteria were selected. No account of any proper motions of the reference stars was made as these contribute errors of much less than a pixel.

4.2 Photometry

For all of the selected objects, standard photometry techniques were used in order to find $\Gamma_{\rm H} \equiv m({\rm H}\alpha) - m({\rm H(cont.)})$ and $\Gamma_{\rm O} \equiv m([{\rm O\,III}]) - m({\rm V})$ (a measure of the magnitude of [OIII] emission). Six concentric apertures (1.00, 1.25, 1.50, 1.75, 2.00, 2.25 pixel radii) were used to produce 'growth curves' for 7 bright reference stars in each of the relevant bands (Hα, [OIII], H(cont.) and V). The middle four apertures were selected as those that would give the most reliable estimates of the required magnitudes. The magnitudes for all 44 reference stars were averaged in each filter so as to give a measure of the zero-point of magnitude for each filter. The 'growth curves' showed a reasonable consistency with each other in terms of general shape and scale and so the H(cont.) magnitude in each aperture was subtracted from the corresponding aperture in the Hα filter. A similar procedure was employed in comparing the [OIII] and V magnitudes. The last three apertures (1.50, 1.75 and 2.00 pixel radii) were found to give consistent values of the required magnitudes and the unweighted mean of the magnitudes in these apertures was taken to give the values presented in the catalogue.

For the Hα magnitudes, an error of 0.3 should be allowed to take into account the uncertainties in the above procedure. This error is derived on the basis of the spread in values for the zero point magnitude for the different apertures discussed above and from the distribution of magnitudes in the final three apertures. A larger error, approximately 0.5, should be allowed for the [OIII] magnitudes as adoption of 'sky' magnitudes in the photometry procedure was found to be very sensitive to the general brightness of the regions surrounding the objects. That is, some objects, which lay in bright regions of the V and [OIII] frames were prone to having a more positive 'sky' magnitude. In cases of gross error, an attempt was made to make an order of magnitude estimate of the sky magnitude for each object by visual inspection of the frames. Clearly this photometry procedure is not well suited to the wide, deep field format of the images. Indeed, some objects were not assigned magnitudes, due, generally, to their appearance in bright regions of the CCD. The given relative magnitudes therefore provide an indication only of the magnitude of Hα and [OIII] line emission.

5 THE CATALOGUE

We present the catalogue of selected objects in Tables 1 and 2. Table 1 contains most of the selected objects and Table 2 regards those objects for which only an estimated pixel number could be obtained as a measure of their position on the image. The format is the same in both tables: the first column gives the object number; the second column gives a short description of the object as it appeared in the images studied; the third and fourth columns give the right ascension (hr min sec) and declination (deg min sec) of the object as determined by the 6-coefficient model in the ASTROMETRY package; the relative magnitudes in the Hα and [OIII] bands, $\Gamma_{\rm H}$ and $\Gamma_{\rm O}$, as determined by the methods discussed in Section 4.2, are given in the fifth and sixth columns. Objects for which no description is given had no defining features or abnormalities in any of the frames.

As a means of checking the accuracy of the positions given in the catalogue, the known PN, very low excitation (VLE) and emission-line stars (from Tables 2 and 3 in MA93) were located in the list of co-ordinates. By comparing the positions given in MA93 and those in the catalogue, the largest discrepancy between the two was found to be 8 arc seconds in declination. This was found for object num-

Table 1. Catalogue of objects with accurate positions (±12 arc seconds). Unless otherwise stated in the description, all objects are candidates for PN. The description code is given below the table. All co-ordinates are J2000.

No.	Description	RA	Dec	Γ_H	Γ_O	No.	Description	RA	Dec	Γ_H	Γ_O
1	Em*	00 27 18.2	-75 10 30	-1.06	0.19	65	SMP13	00 49 51.5	-73 44 20	-3.31	-3.13
2		00 31 40.8	-73 47 45	-3.64	-2.43	66	B	00 50 01.3	-73 15 40	-3.61	-2.20
3	SMP2	00 32 38.2	-71 41 56	-3.16	-3.39	67	Em*	00 50 11.7	-72 32 34	-2.82	-0.36
4	F(Hα), Em*	00 34 09.9	-70 59 44	-0.71	-0.06	68	[MA93]340	00 50 12.8	-73 28 45	-1.35	-1.03
5	SMP3	00 34 22.6	-73 13 19		-2.39	69		00 50 17.2	-72 24 03	-1.69	-0.12
6	Em*	00 37 14.8	-73 00 16	-4.14	-0.38	70	[MA93]349?	00 50 17.5	-72 24 12	-2.12	0.05
7	CCD	00 40 01.0	-73 45 07	-1.44	-0.28	71		00 50 26.4	-73 29 45	1.18	
8	Em*	00 40 36.0	-71 57 52	-1.07	-0.18	72	[MA93]366	00 50 27.7	-73 30 15	-0.85	0.12
9	SMP4?, G	00 40 45.9	-75 16 16	-2.78	-3.34	73		00 50 28.5	-73 29 32	-0.38	
10	SMP5	00 41 21.8	-72 45 16		-4.10	74	[MA93]385	00 50 43.9	-73 27 05	-2.89	0.01
11	SMP6	00 41 28.4	-73 47 06		-3.02	75	[MA93]392	00 50 46.1	-73 08 07	-1.95	-0.32
12	L	00 42 20.9	-73 44 17	-3.60	-1.01	76	[MA93]395	00 50 47.9	-72 10 17	-1.70	0.25
13	SMP7?	00 42 30.8	-73 20 56	-1.33	-1.38	77		00 50 48.6	-73 24 21	-2.51	-0.14
14	[MA93]41	00 42 35.6	-73 47 57	-1.40	-0.30	78		00 50 48.7	-72 34 33	-3.45	
15	[MA93]43	00 43 03.9	-72 35 50	-1.76	0.41	79	Em*	00 50 49.9	-72 42 24	-0.50	0.02
16	Em*	00 43 06.2	-73 20 37	-1.56	-0.13	80	Em*	00 51 04.7	-73 15 05	-0.54	0.10
17	SMP8	00 43 25.4	-72 38 20		-3.62	81	SMP15	00 51 07.5	-73 57 35	-0.92	-3.20
18	-54-	00 43 36.5	-73 02 27	-2.29	-1.30	82	[MA93]439	00 51 08.5	-72 25 31	-1.37	0.51
19	Sus.([OIII])	00 44 23.8	-73 27 52			83	Dp, Em*	00 51 16.9	-72 43 34	-1.33	-0.13
20	Em*	00 44 37.4	-70 47 55	-0.31	0.53	84	SMP16	00 51 27.8	-72 26 19		-1.29
21	[MA93]84	00 44 56.4	-73 22 55	-1.64	-0.03	85	[MA93]477	00 51 34.1	-73 05 32	-0.88	0.14
22	Em*	00 44 57.2	-73 59 03	-1.90	-0.28	86	[MA93]482	00 51 36.0	-73 20 11	-0.74	0.19
23	[MA93]92	00 45 03.4	-72 42 00	-1.82	0.09	87	Em*	00 51 36.8	-73 18 32	-0.42	-0.09
24	-104-	00 45 28.0	-73 42 14	-1.03	-0.37	88		00 51 41.6	-73 13 36	-4.64	-2.35
25	Em*	00 46 05.3	-75 20 21		0.10	89		00 51 47.8	-72 50 46	-3.34	-2.07
26	F([OIII]), B	00 46 11.0	-73 25 39			90	SMP17	00 51 56.7	-71 24 43	-4.48	-3.30
27	B, [MA93]128	00 46 17.2	-73 12 40	-2.76	-0.51	91	SMP18	00 51 58.3	-73 20 34	-1.28	-1.51
28	L, B	00 46 17.3	-73 23 30	-3.02	-1.75	92	B, Em*	00 51 59.9	-72 16 38	-2.65	-1.71
29	B, Em*	00 46 27.0	-73 12 49		-0.11	93	[MA93]521	00 52 00.9	-72 55 31	-1.40	0.25
30		00 46 33.3	-73 06 01	-3.70	-2.75	94	F([OIII]), Em*	00 52 11.5	-73 36 04	-2.31	-0.09
31	L region	00 46 39.1	-73 31 42	-2.67	-1.90	95		00 52 12.4	-72 41 33	-3.03	-1.17
32	F([OIII])	00 46 55.3	-73 08 36	-2.83	-0.05	96	[MA93]559	00 52 16.9	-72 08 46	-0.92	-0.01
33	B	00 46 56.8	-73 10 56	-1.57	0.11	97		00 52 24.3	-72 36 02		
34	SMP10	00 46 59.6	-72 49 20	-0.15	-0.04	98		00 52 25.9	-72 36 30		
35	B, [MA93]160	00 47 08.6	-73 14 16	-1.12	0.36	99	CCD	00 52 25.9	-73 47 33	-4.40	-0.50
36		00 47 29.1	-73 22 31	-4.05	-4.67	100		00 52 27.4	-73 33 58	-0.69	-0.09
37		00 47 30.7	-73 05 02	-3.17	-3.04	101	B, [MA93]574	00 52 29.2	-72 11 01	-0.75	-0.13
38	Em*	00 47 37.5	-73 33 24		-0.47	102		00 52 31.1	-72 37 54	-2.03	-0.64
39	CCD	00 47 46.4	-73 29 23	-0.27	-3.14	103		00 52 34.2	-72 16 56	-0.97	-0.11
40		00 47 48.9	-73 17 32	-3.39	-1.83	104	B, [MA93]586	00 52 35.4	-72 11 53	-0.83	-0.02
41		00 47 58.4	-73 17 50	-4.14	-2.38	105	[MA93]585	00 52 35.5	-72 09 33	-1.01	-0.47
42	Em*	00 47 59.0	-72 31 58	-1.64	0.42	106		00 52 37.6	-72 38 15		
43		00 48 03.6	-73 16 30	-3.58	-3.01	107	[MA93]590	00 52 37.8	-72 27 43	-1.93	-0.11
44	[MA93]204	00 48 07.0	-73 46 43	0.83	-0.23	108	[MA93]592	00 52 38.1	-73 26 16	-2.84	-0.69
45		00 48 08.6	-73 14 35	-4.61	-2.89	109	CCD, Em*	00 52 52.6	-73 47 34	-0.30	-0.32
46	B	00 48 09.0	-73 14 17	-4.36	-2.91	110	[MA93]629	00 52 58.4	-73 17 09	-1.65	
47		00 48 11.1	-73 19 48	-3.89	-2.65	111	Sus.	00 53 02.0	-72 53 47	-2.14	-1.07
48	[MA93]219	00 48 20.9	-72 51 15	-0.69	-0.03	112		00 53 02.8	-72 39 11	-1.60	-0.27
49	Em*	00 48 22.7	-73 31 49		0.14	113	Em*	00 53 08.4	-72 39 31	-1.69	-0.48
50	[MA93]223	00 48 22.8	-72 43 53	-1.51	-0.18	114	SMP19	00 53 11.6	-72 45 01	-3.49	
51	B	00 48 29.1	-73 16 06	-4.63	-3.12	115	B	00 53 16.5	-72 53 31	-2.23	-2.11
52	B	00 48 34.0	-73 15 11	-3.83	-2.82	116		00 53 25.9	-72 28 24	-2.57	-1.02
53	Em*	00 48 35.9	-72 52 57	-1.20	-0.24	117	[MA93]681	00 53 32.0	-72 15 09	-1.59	-0.03
54	SMP11	00 48 36.6	-72 58 03	-2.28	-0.87	118		00 53 35.6	-73 10 04	-2.80	0.13
55	Em*	00 48 37.2	-72 11 41	-0.68	-0.04	119	[MA93]691	00 53 37.2	-72 38 32	-2.08	0.15
56	B	00 48 40.5	-73 16 08			120		00 53 41.4	-72 39 32	-3.43	-0.72
57	B, L region	00 48 54.8	-73 07 49	-3.94	-2.22	121	Em*	00 53 43.8	-72 53 31	-0.15	0.20
58	Em*, B	00 49 14.1	-73 14 56	-1.54	-0.19	122		00 53 45.1	-74 49 04	3.02	0.33
59	B, [MA93]309	00 49 37.7	-73 06 13	-1.22	-0.03	123	F	00 53 50.0	-72 11 06	-1.89	-0.17
60	Em*	00 49 38.2	-74 17 33	-0.27	-0.05	124		00 53 54.0	-72 22 23		-2.31
61		00 49 41.4	-72 48 45	-3.87	-0.89	125	B, L region	00 53 57.9	-72 43 55	-3.03	-2.76
62	15arc″	00 49 43.4	-73 10 33	-2.04	-1.83	126	Em*	00 54 12.5	-72 22 17	-0.33	0.04
63	15arc″, Em*	00 49 43.6	-73 26 50	-0.67	0.10	127	L(Hα)	00 54 15.5	-73 17 04	-3.69	-1.37
64		00 49 50.3	-73 24 06	-2.67	-1.23	128	Em*	00 54 21.7	-72 17 26	-1.68	-0.07

Table 1. —*continued*

No.	Description	RA	Dec	Γ_H	Γ_O	No.	Description	RA	Dec	Γ_H	Γ_O
129	Em*	00 54 23.6	-71 58 09	-1.74	-0.04	193		01 00 42.6	-71 31 14	-1.99	-0.10
130	Sm, [MA93]778	00 54 37.8	-72 13 38	-1.91	-0.34	194	[MA93]1222	01 00 46.0	-72 29 57		0.10
131	[MA93]779	00 54 37.8	-72 32 07	-3.01	0.42	195		01 00 50.4	-72 03 28	-1.30	-0.70
132		00 54 44.4	-72 47 34	-2.59	-0.88	196	[MA93]1230	01 00 57.1	-72 16 35	-0.89	-0.04
133		00 54 45.4	-72 40 08	-1.66	-0.78	197	[MA93]1235	01 00 58.9	-72 30 47	-1.03	0.00
134	[MA93]798	00 54 46.2	-72 25 24	-3.16	-0.26	198	[MA93]1263	01 01 26.2	-72 34 02	0.28	-0.02
135	[MA93]804	00 54 48.9	-72 24 21	-1.34	0.19	199	[MA93]1262	01 01 26.2	-71 46 39	-1.46	0.16
136	Em*	00 54 53.6	-73 34 00	-2.59	0.25	200	[MA93]1267	01 01 29.7	-72 23 23	-1.64	-0.27
137	[MA93]812	00 54 58.5	-72 20 00	-1.28	0.02	201		01 01 30.6	-72 23 21	-1.11	-0.28
138		00 54 60.0	-72 19 48	-1.28	0.11	202	L	01 01 32.9	-71 50 55	-2.06	-0.97
139	[MA93]814	00 55 00.3	-72 56 16	-1.31	-0.02	203	[MA93]1272	01 01 33.3	-72 09 19		0.14
140	[MA93]821	00 55 10.6	-72 03 56	-0.86	0.17	204	Em*	01 01 35.7	-71 56 51	-1.90	-0.28
141	Em*	00 55 11.2	-70 38 24	-4.66	0.61	205	Em*	01 01 40.4	-72 02 25	-2.45	-0.21
142		00 55 11.7	-73 26 50	-1.36	0.08	206		01 01 51.0	-74 42 36	-0.91	-0.98
143	[MA93]867	00 55 41.8	-72 23 26	-1.72	-0.28	207	Em*	01 02 04.8	-72 19 11	-1.05	-0.15
144	Em*	00 55 44.6	-72 16 11	-1.94	-0.17	208	[MA93]1302	01 02 07.3	-71 30 05	-0.34	-0.08
145	[MA93]876	00 55 49.1	-72 25 25	-0.30	-0.29	209		01 02 07.7	-75 00 18		-1.67
146	[MA93]882	00 55 54.2	-72 08 57	-2.56	0.00	210	[MA93]1307	01 02 14.4	-72 22 12		0.09
147	Em*	00 55 54.6	-73 22 32	0.11	-0.07	211		01 02 25.0	-72 08 41	-0.79	-0.53
148	B	00 56 01.5	-72 19 50		-1.20	212	F([O III])	01 02 29.9	-73 27 44		-0.38
149		00 56 13.6	-72 18 05	-0.49	-0.83	213	F([O III]), Em*	01 02 37.9	-72 50 56	-1.22	0.04
150	[MA93]952	00 56 15.4	-72 38 00	-0.50	-0.11	214	Em*	01 02 41.1	-71 59 50	-2.17	0.00
151	B, Em*	00 56 17.1	-72 47 30	-4.10	-0.77	215	Em*	01 02 46.6	-71 56 17	-1.99	-0.53
152		00 56 19.0	-72 17 29	-2.99	-1.80	216	B, L	01 02 49.4	-71 53 20	-4.06	-2.55
153	Em*, I	00 56 21.1	-72 50 39	-1.79	0.05	217	L, Em*	01 02 53.7	-72 24 49	-2.68	-0.39
154		00 56 41.8	-72 56 29	-1.63	-1.99	218	[MA93]1338	01 02 54.7	-71 57 32	-2.74	-0.40
155		00 56 52.2	-71 56 15	-0.15	-0.20	219	[MA93]1351	01 02 59.3	-72 25 34	-3.15	0.15
156	L	00 57 03.4	-73 34 06	-3.33	-1.98	220	[MA93]1354	01 03 04.1	-72 54 17	-1.37	0.02
157	[MA93]981	00 57 07.6	-72 13 20	-0.83	-0.56	221		01 03 05.1	-71 53 31	-5.41	-1.96
158	Em*	00 57 08.4	-73 34 21	-1.12	-0.64	222		01 03 07.4	-72 06 25	-4.49	-2.42
159		00 57 18.1	-71 54 25	-1.26	-1.48	223	[MA93]1362	01 03 08.5	-72 14 07	-3.03	-0.41
160		00 57 20.9	-71 09 55	-0.58	-0.25	224	Em*	01 03 11.5	-72 16 20	-0.52	-0.11
161	[MA93]1000	00 57 23.6	-72 01 37		0.02	225	[MA93]1366	01 03 12.9	-72 39 08	-0.43	0.11
162	-1011-	00 57 30.1	-72 32 25	-2.67	-2.12	226		01 03 21.9	-74 00 00	-0.23	-1.30
163	[MA93]1035	00 57 49.2	-72 22 45	-0.93	0.02	227		01 03 23.9	-73 59 58	-0.33	-1.17
164	B	00 57 56.6	-72 39 21	-4.08	-1.94	228	[MA93]1374	01 03 24.1	-72 54 11	-1.14	-0.05
165	15arc″	00 57 57.3	-73 34 19		-0.84	229	S	01 03 25.3	-74 58 37		
166	B	00 58 16.6	-72 38 56	-4.37	-3.42	230	Em*	01 03 26.4	-72 38 59	-0.81	-0.15
167	[MA93]1066	00 58 17.9	-72 18 51	-0.74	-0.59	231	[MA93]1408	01 03 48.9	-72 13 03	-1.62	0.04
168	Em*	00 58 22.7	-72 24 29	-1.39	-0.61	232	[MA93]1417	01 03 52.6	-72 43 42	-0.70	-0.02
169	B	00 58 26.2	-72 39 54	-4.67	-2.27	233		01 03 57.6	-72 41 11	-3.74	-0.78
170	Em*	00 58 31.5	-71 44 50	0.02	-0.10	234	[MA93]1433	01 04 01.1	-72 33 12	-1.12	0.02
171	SMP22	00 58 37.5	-71 35 50	-1.65	-2.31	235	CCD, GXS	01 04 11.2	-74 43 19	-0.62	-3.09
172	SMP23	00 58 42.8	-72 56 59			236	[MA93]1452	01 04 17.1	-72 26 20	-1.15	0.23
173	-1091-	00 58 42.8	-72 27 17	-4.09	-2.62	237	SMP26	01 04 17.7	-73 21 45	-1.87	-1.71
174	15arc″	00 58 43.9	-73 34 19		-0.77	238	[MA93]1475	01 04 40.5	-72 20 03		0.39
175	[MA93]1107	00 58 54.9	-71 56 47	-1.19	-0.15	239	[MA93]1515	01 05 07.6	-72 48 07	-1.03	0.00
176		00 58 57.3	-72 14 41		-0.59	240	[MA93]1516	01 05 07.7	-72 24 40	-2.19	0.00
177	Em*	00 59 11.9	-74 49 24	-0.15	-0.46	241	S	01 05 13.5	-71 11 41		
178	F([O III])	00 59 13.0	-72 24 18	-4.35	-2.20	242	B, [MA93]1543	01 05 41.8	-72 03 42	-2.36	-0.37
179	Em*	00 59 13.3	-71 38 41	-0.91	-0.09	243	[MA93]1552	01 05 47.5	-71 46 21	-2.16	0.04
180	L	00 59 13.6	-72 30 55	-2.38	-2.60	244		01 06 01.0	-72 00 47	-1.38	-0.45
181	SMP24	00 59 16.1	-72 02 00	-4.68	-2.89	245	[MA93]1575	01 06 16.0	-72 57 40	-1.22	0.16
182		00 59 21.8	-74 16 00	-2.18	-1.12	246	Em*	01 06 29.7	-72 22 09	-0.39	-0.11
183		00 59 25.5	-72 17 45	-1.30		247	[MA93]1591	01 06 33.4	-72 17 23	-0.79	0.60
184		00 59 29.3	-72 01 06	-3.75	-0.03	248	[MA93]1598	01 06 40.1	-73 10 22	-1.88	0.03
185		00 59 33.7	-73 30 17		-1.97	249	[MA93]1603	01 06 49.7	-71 58 56	-1.86	-0.10
186	SMP25	00 59 40.9	-71 38 14	-0.82		250	[MA93]1620	01 07 14.2	-72 25 44	-0.65	0.23
187	F	00 59 52.4	-74 41 05	-0.31	-1.46	251	15arc″, Em*	01 07 14.5	-72 20 45	-1.04	-0.21
188	[MA93]1174	01 00 01.9	-72 55 21		-0.13	252	Em*	01 07 32.7	-72 17 40	-0.55	-0.19
189	[MA93]1188	01 00 08.7	-71 48 04	-4.04	0.13	253	[MA93]1635	01 07 37.3	-72 20 04	-2.01	-0.14
190	[MA93]1192	01 00 13.4	-71 34 08	-2.41	-0.16	254	[MA93]1639	01 07 42.4	-72 21 46	-0.80	-0.09
191	Em*	01 00 24.6	-71 37 00	-4.71	-0.01	255	B	01 08 28.9	-72 00 12	-4.17	-1.64
192	[MA93]1208	01 00 29.4	-72 20 33	-1.46	-0.01	256	[MA93]1677?	01 08 43.6	-73 14 36	-1.32	-0.30

Table 1. —*continued*

No.	Description	RA	Dec	Γ_H	Γ_O	No.	Description	RA	Dec	Γ_H	Γ_O
257	F, G	01 08 56.9	-74 44 17			288	Em*	01 23 57.7	-73 21 28	-0.20	0.11
258	B	01 09 13.0	-73 11 37	-4.32	-3.25	289	G	01 24 07.6	-73 09 05	-4.44	-3.26
259	G	01 09 17.7	-71 23 59	-2.60	-2.32	290	SMP 28	01 24 10.7	-74 02 29	-2.93	-1.45
260	Sus.	01 09 24.4	-72 20 51	-2.49	-0.10	291	Em*	01 24 21.8	-73 31 51	0.54	0.10
261	[MA93]1717	01 10 19.9	-72 24 27	-6.33	0.23	292	Em*	01 24 41.7	-73 50 09	-0.06	-0.10
262	[MA93]1739	01 11 12.5	-71 57 19	-1.04	0.13	293	Em*	01 24 51.5	-73 34 06	-1.27	0.00
263	[MA93]1744	01 11 25.1	-71 58 37	-1.76	-0.12	294	B(Hα)	01 25 18.4	-73 16 28	-1.43	-0.62
264		01 11 25.2	-72 09 45	-2.88	-1.72	295	Em*	01 27 01.5	-73 04 35	-1.19	0.06
265	[MA93]1749	01 11 44.5	-73 13 51	-0.67	-0.02	296	Em*	01 27 21.1	-73 10 51	-0.36	-0.12
266	Em*	01 11 44.8	-74 40 02	-0.01	0.15	297	Em*	01 27 37.7	-73 24 03	-0.37	0.13
267	[MA93]1759	01 12 19.1	-73 51 24	-2.21	0.21	298	Em*	01 27 45.3	-73 32 57	-1.22	-0.18
268	Em*	01 12 23.6	-70 46 12	-0.49	0.64	299	L, S	01 27 58.4	-73 28 22		-10.06
269	[MA93]1763	01 12 52.8	-73 30 21	-1.04	-0.37	300	Em*	01 29 17.5	-72 43 20	-1.86	0.05
270	F([O III])	01 12 54.9	-73 29 23			301		01 29 26.4	-73 33 34	-3.23	-2.27
271	Em*	01 13 07.4	-74 12 27	0.39	0.02	302	Em*	01 29 37.1	-75 13 16	-0.26	0.19
272	F, G	01 13 11.0	-74 55 22	-1.51	-3.15	303	Em*	01 29 52.9	-71 26 23	-0.40	0.69
273	B	01 13 47.3	-73 17 44	-3.49	-2.66	304	Em*	01 30 03.5	-71 48 45	-0.66	0.86
274	B	01 14 37.6	-73 18 23	-3.85	-2.66	305	Em*	01 31 26.1	-71 42 40	-0.12	0.12
275		01 14 40.8	-73 17 20	-4.47	-3.50	306	Em*	01 31 28.7	-72 48 15	-0.08	-0.08
276	[MA93]1808?	01 15 14.7	-73 28 30	-0.86	-0.03	307	Em*	01 31 45.5	-74 53 44	-0.26	0.32
277	Em*	01 15 20.2	-70 32 44	-0.16	0.13	308	Em*	01 31 50.8	-73 21 32	-0.30	0.18
278	Em*	01 15 23.1	-73 30 35	0.09	0.04	309	Em*	01 32 04.6	-71 25 11	-0.34	0.12
279		01 15 53.2	-73 31 21	-0.94	0.00	310	Em*	01 32 24.7	-75 02 37	-0.26	0.16
280	Em*	01 16 26.3	-71 19 29	-0.88	-0.01	311	Em*	01 33 47.0	-74 35 42	-0.65	-0.14
281	Em*	01 18 24.6	-73 31 10	-0.09	-0.23	312		01 33 51.8	-75 06 24	-0.16	0.14
282	I, G	01 18 53.6	-71 24 56			313	Em*	01 34 17.0	-73 58 14	-0.06	0.03
283	Em*	01 20 13.7	-74 59 10	-0.06	0.11	314	Em*	01 34 46.6	-73 49 19	-0.70	0.18
284	Em*	01 20 43.9	-73 33 38	-0.84	0.09	315	Em*	01 36 50.2	-75 08 13	-0.17	0.13
285	SMP27	01 21 10.7	-73 14 33	-3.27	-2.46	316	Em*	01 37 07.3	-74 45 48	-0.37	0.17
286	Em*	01 23 32.4	-73 44 49	-1.08	0.14	317	Em*	01 39 15.1	-74 37 27	-0.21	0.06
287	Em*	01 23 41.1	-71 19 31	-0.36	0.19	318	Em*	01 40 07.5	-74 51 20	-0.05	0.17

G – A good candidate for a planetary nebula. The object had a Gaussian-like profile and had significant flux in all frames.

Em* – Emission-line star. This represents a candidate for an Hα emission-line star. These objects were not identified in MA93.

SMP *xx* – A known emission-line star. These objects lay outside the survey range of MA93. We therefore use the co-ordinates in the SMP78 catalogue. A question mark (?) indicates the same uncertainty as described for [MA93]*xxxx*.

-*xxxx***-** – Indicates that the object is identified in MA93 as a PN with the identifier *xxxx* and was not identified in SMP78.

[MA93]*xxxx* – A known emission line star identified in MA93 and numbered accordingly. If a question mark (?) is appended to the identifier then the co-ordinates are different by slightly more than 12 arc seconds from the known J2000 co-ordinates. Thus, some uncertainty exists as to whether the identification is correct.

B – Bright region. The object appeared in a bright region of the frame and so should be treated with some caution. May be specified for a particular filter.

CCD – Bad CCD line or fault in CCD. This means that the object lies close to a CCD fault in the images.

Dp – Different positions. This indicates that the centroids in the Hα and [O III] images were ~ 1 pixel apart. These should be treated as suspect.

F – Faint. This means that the object had low peak pixel value compared to the background. A filter may be specified if the object was only faint in one filter.

I – Irregular shape. The object did not have a Gaussian-like profile. May be specified for a particular filter.

L – Large. The object is more than 2.5 pixels FWHM. This means that a large area may have to be searched in subsequent observations in order to find the emission object. Indeed, there may be several emission objects around the given co-ordinate. May be specified for a particular filter. A variation on this description is "L region", meaning that the given co-ordinate is the centroid of an area (at least 5 pixels FWHM) where many emission objects may be located. Usually, this is also a "bright" region.

S – Possibly a star. It was not clear from the images whether this object is a star or not, due to the problems outlined in Section 4.1.

Sm – Small. This means that the object is contained within just one pixel. May be specified for a particular filter.

Sp – Spread out. The object is reasonably faint and has a large FWHM (usually > 2 pixels). May be specified for a particular filter.

Sus. – The object in question had some feature that made it seem unlikely that there was a genuine object at the given position. A particular frame may be specified.

15 or **25 arc″** – A 15 or 25 arc second error should be allowed for the RA and Dec.

Table 2. These objects only had an estimated pixel number assigned to them (i.e. no Gaussian fit was performed in position finding). A 15 arc second error ($\sim 3\sigma$) in position should be allowed for these objects unless otherwise marked.

No.	Description	RA	Dec	Γ_H	Γ_O	No.	Description	RA	Dec	Γ_H	Γ_O
319	Em*	00 31 00.5	-73 15 22	-1.44	-0.03	346		00 54 26.1	-73 13 11	-0.72	0.14
320	Em*	00 38 38.5	-73 27 03	-0.97	0.17	347	[MA93]788	00 54 42.6	-73 45 45	-2.64	0.45
321	[MA93]19	00 40 43.8	-73 03 46	-1.77	0.24	348	[MA93]809	00 54 55.8	-72 45 06	-0.06	-0.27
322	Em*	00 41 30.7	-72 10 56	-0.98	0.05	349		00 54 57.4	-74 47 59	-2.52	
323	Em*	00 45 04.7	-73 30 09	-0.72	0.00	350	Em*	00 55 37.9	-75 10 11	-0.96	0.17
324	[MA93]97	00 45 19.4	-73 29 59	-4.23	0.14	351		00 55 40.3	-72 45 04	-0.83	-0.09
325	[MA93]105	00 45 27.9	-73 30 14	-1.59	-0.27	352	[MA93]959	00 56 42.7	-72 44 25	-3.19	-0.16
326	Em*	00 46 34.4	-73 39 20	-0.45	-0.11	353		00 57 07.1	-73 44 37	-0.73	-0.58
327	Em*	00 47 35.1	-72 16 12			354	[MA93]987	00 57 13.5	-72 38 52	-2.09	-0.79
328	[MA93]286	00 49 14.8	-71 54 52	-0.76	-0.11	355	[MA93]1001	00 57 24.6	-72 39 05	-1.59	-0.60
329	SMP12	00 49 20.3	-73 52 57		-2.62	356	[MA93]1051	00 58 03.3	-72 37 51	-1.40	-0.11
330		00 49 39.6	-72 39 52	-1.28	-1.35	357		00 59 21.1	-72 45 15	-0.26	0.04
331	[MA93]357	00 50 23.9	-72 01 14	-1.31	-0.06	358	Em*	00 59 27.0	-72 48 39	-2.32	-0.33
332	[MA93]394	00 50 47.3	-71 49 20	-0.56	0.17	359	[MA93]1155?	00 59 33.3	-72 23 24	-0.61	-0.01
333	[MA93]457	00 51 24.9	-72 17 14	-1.34	-0.11	360	[MA93]1172	00 59 57.9	-71 58 27	-1.32	-0.06
334	Em*	00 51 48.1	-73 55 00	-0.29	0.14	361	Em*	01 00 22.6	-75 19 18	0.07	-0.16
335	[MA93]515	00 51 57.5	-72 09 03	-0.65	0.10	362		01 01 19.2	-72 36 30		-0.19
336	[MA93]551	00 52 13.2	-71 45 11	-2.62	-0.06	363		01 02 15.2	-71 51 38		-1.22
337	Em*	00 52 14.7	-73 04 52	-0.33	-0.40	364		01 02 31.0	-72 59 18		
338	25arc″, Em*	00 52 47.5	-72 12 51	-0.59	-0.10	365		01 02 48.3	-74 45 49	-1.54	-1.91
339		00 52 55.6	-73 00 41	-0.88	-0.25	366		01 03 00.8	-73 15 08	-1.61	-1.27
340	[MA93]634	00 52 59.5	-73 16 22	-1.01	0.56	367	[MA93]1363	01 03 10.0	-72 57 48	-0.64	0.13
341		00 53 18.7	-74 21 18			368	Em*	01 04 23.8	-71 01 51	-0.21	0.12
342	-700-	00 53 42.9	-73 37 02		-1.90	369	[MA93]1566?	01 06 05.4	-71 51 40	-1.41	-0.08
343	Em*	00 53 44.0	-73 10 27	-0.37	0.06	370	Em*	01 07 49.2	-72 12 49	-0.61	0.09
344		00 53 44.8	-73 12 38	-1.85	-0.75	371		01 09 42.5	-73 52 36		-4.38
345		00 54 00.5	-74 37 13	-0.69	-1.26	372	G	01 11 22.3	-74 30 05	-0.42	-2.23

ber 16 in the SMP78 table which was initially described as being 'spread out' upon visual scanning of the SMC frames. Thus, it is expected that most objects in the catalogue will lie within 12 arc seconds of their calculated position – the assigned error is likely to represent an $\sim 3\sigma$ circle of uncertainty.

It must be noted that not all possible or proven planetary nebulae given in MA93 and SMP78 were found by the methods used to scan the SMC frames. The known objects that were not found were later identified on the image by using the MA93 and SMP78 co-ordinates and the ASTROMETRY procedure in reverse. The objects were then visually inspected and it was determined as to why they were not found in the initial scanning procedure. The primary reasons are given below:

(i) The object was too faint to be confidently identified in all frames. Usually, the object did not even appear to be present in SURFACE PLOT and, if a slight peak could be detected, it was largely swamped by the background noise.

(ii) Often, the object appeared near a stellar feature and was partially subtracted in the Hα images due to the problems outlined in Section 4.1.

(iii) Objects were often found to be in such bright regions of the SMC frames that it was impossible to determine whether the objects were present or not.

(iv) Most of the "New PN" and VLE objects in MA93 appeared at the specified position in the Hα images but could not be found by any method in the [OIII] image.

Of the 62 proven or probable SMC planetary nebulae and VLE objects given in MA93, 19 are found in the current catalogue. The SMP78 catalogue spans a larger area of the sky and contains 7 objects which are not included in the MA93 table for this reason. Of these 7, 3 were identified in our catalogue plus 1 object which lay slightly beyond our permitted positional error of 12 arc seconds. It is noted that many of these known objects were regarded as being possible stars or faint objects in our visual scan and some were objects to which only an estimated pixel row and column could be assigned. It is difficult to estimate what fraction of the 107 hitherto unidentified PN candidates (131 candidate PN with $19 + 4$ previously identified) will be new PN or VLE objects. Our detection rate for previously identified objects is 33% but this gives no view of the detection rate for *unidentified objects*. We note that, if approximately half of our candidates are in fact PN, from the PN luminosity function of Ciardullo et al. (1989), the total number of PN within the SMC should be > 2500. This is less than their estimate for the number in the Galaxy but significantly greater than their estimate for the bulge of M31. There are also a number of Hα emission-line objects listed in the catalogue that were not found in Table 2 of MA93. Again, the field of the present survey was larger than that presented in MA93 and so there are quite a number of objects which are previously unidentified towards the beginning and end of the catalogue. Spectra of these objects and the planetary nebulae candidates must therefore be measured so that they may be more precisely identified.

One may also ask how our survey can detect objects that were not detected in the SMP78 and MA93 surveys

which had similar detection limits. The answer may lie partly with the fact that we have used CCD imaging rather than photographic imaging as used in previous surveys. CCD imaging is a more powerful tool for finding strong Hα sources on sub-pixel scales. However, weaker Hα objects in crowded regions of the sky will not be detected with our methods. Only spectroscopic observations and the use of new Anglo Australian Observatory Schmidt Hα images can answer this question. Such work is now being undertaken.

6 CONCLUSION

A catalogue of candidates for PN, VLE objects and Hα emission-line objects in the SMC has been compiled from a visual scan of wide field, deep, narrow band images. Images were taken in the Hα, [OIII], red continuum and V band filters and non-stellar objects appearing in both the Hα and [OIII] bands, but not in the continuum-subtracted [OIII] image, were taken as good candidates for PN. The magnitude of the emission in each band, relative to the continuum for that band, was estimated via a standard photometry procedure. These results are also given in the catalogue and carry an estimated ± 0.3 error for the Hα band and ± 0.5 for the [OIII] band.

Of the 69 possible or proven planetary nebulae and VLE objects known in the field of the survey (MA93, SMP78), only 23 are found in the catalogue. This is due entirely to the limitations of the wide field CCD format of the images. In total, 236 objects of unknown identity appear in the catalogue. The catalogue contains 107 previously unknown PN candidates and 218 emission line star candidates, only 113 of which are known. We can make no definitive estimate of the fraction of our candidates that will be true PN or VLE objects. However, we note that if only one half of our PN candidates are in fact PN, estimates of the total number of PN in the SMC (> 2500) seem much larger than the values suggested by common wisdom ($\sim 500 - 1000$).

In order to determine the true identity of the catalogued objects, follow-up observations of each object must be made. This may be difficult in some cases due to the relative imprecision of the object co-ordinates (we allow a 12 arc second error for most objects). However, these observations must be carried out in order to obtain a better survey of the planetary nebulae content of the SMC and to evaluate the viability of the methods used to find the objects. Several observations subsequent to the formation of the catalogue have revealed that many of the potential PN objects are indeed PN. A disadvantage of the wide field format of the SMC images was apparent in many cases: more than one object occupied the 12 arc seconds surrounding the catalogue co-ordinates. Details of these observations will be published elsewhere. However, the usefulness of the catalogue in Tables 1 and 2, as a supplement to those in MA93 and SMP78, is clear. The methods of finding PN detailed in Sections 2–4 will be applied to the Large Magellanic Cloud where we have already retrieved the data. Also, by comparing different narrow band images to those used here, many more emission objects, such as Be stars, could be identified in the Magellanic Clouds.

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